RCUBE - A MULTIPURPOSE PLATFORM FOR MOBILE SYSTEMS IN EDUCATION

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Abstract

Since 1995 mobile robot systems have been investigated and included in the education process. Using commercial and/or open source platforms like LEGO-techniques with the 6.270-Board [5], the EyeBot controller [3] or the PIONEER robots [10] various aspects of mobility, sensing, control and navigation were taken into account. The limited abilities of all these platforms in computing power or image processing required the development of a new hardware platform called RCUBE [2], [11] combining the features of a typical actuator-sensor-input-output-board with computing power and image recognition capabilities. The system is suitable as a compact platform for universities, small enterprises and private developers.

Key words: Autonomous mobile robots, Controllers, Navigation, Intelligence, Hardware.Introduction

I. Introduction

The fascination of mobile robots has continued since the famous science fiction of Karel Capek and Isaac Asimov, the beginning of legged robots in the early eighties and the humanoids at the end of the nineties up to the actual American Mars mission with the robots Spirit and Opportunity. The success and the failure are discussed.

Mobile robot systems have been investigated and developed at high specialised laboratories in research institutes, universities and companies. A number of service or personal robots have found their way into our world. They can be met in big halls cleaning the floor or the windows, in parking houses watching for troubles, in forests bringing in wood or at the Robot-Soccer World Cup.

Various principles of mobility from wheeled over legged up to flying mechanisms, different sensors and sensor systems from simple switches over ultra sonar up to stereo cameras, several hard- and software architectures from standby computer systems up to high integrated embedded microprocessor platforms were developed, built in changing configurations and tested in ideal, industrial or hazardous environments.

Consequently, Robotics - the scientific discipline about the understanding and the development of robots – was included into Mechanical, Electrical, Mechatronic Engineering or Computer Sciences Bachelor and Master courses.

In this paper mobility is treated from the point of view of the built mechanism and its possibility to move, its tractability and controllability, navigation and autonomy. Beside of the mechanics the main problems using standard hardware platforms for small robots were their limited abilities like not enough connectors to sensors and actuators, low computing performance, high power consumption, lack of onboard image recognition capability and energy autonomy. Some examples of using mobile robots in the education process at the University of Applied Sciences Brandenburg are presented.

The new developed hardware platform RCUBE combining the features of a typical actuator-sensor-input-output-board with computing power and image recognition capabilities is flexible, adaptable to an application case, easy to program and cost-effective.

II. Mobile LEGO-robots

In 1996 the concept of Learning Engineering by Designing LEGO Robots described in [5], [6] was introduced. The robots are composed of mechanical elements of the LEGO constructor system, of wheels and gears, of DC-and servo motors, of a variety of

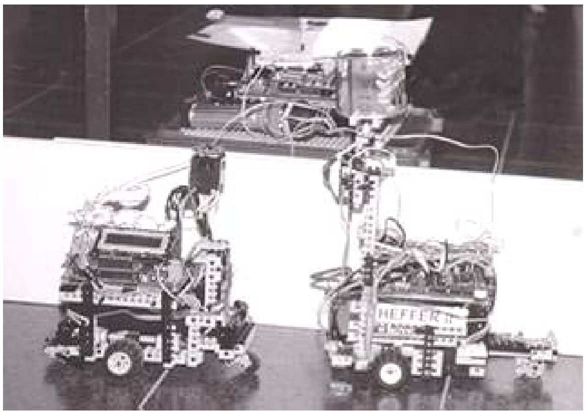

Fig. 1. Robot-Hunter and Robot-Hare

cheap sensors like switches, photo elements, infrared transmitters and receivers, batteries and a 6.270-Board with analogous and digital inputs & outputs. The action control algorithms - the intelligence of the robot - are implemented at a usual personal computer using the high level “Interactive C” programming language [1].

In short time projects similar to real once where new products are developed in limited time with limited budgets using commercial subsystems teams of students of different specialisations have to create mobile and autonomous robots for given tasks contrary in their demands. For example:

Hunting of a Robot-Hare (Fig. 1): 3 robots are included in the competition, one - the hare – is running away from the others – the hunters. Each of them has to localise the other both. Collision between the hunters should be avoided. The competition ends if there is a hunter clashed with the hare or if the time is over. Different tasks have to be solved:

- build a fast and robust mechanism,
- use an infrared beamer and receiver for self localisation relatively to the other robots,
- avoid collision and
- find out a hunting strategy.

Two different concepts were dealt with:

- to create multipurpose robots equipped with a full set of possible sensors and a functional library for various sensors and motion commands or
- to develop a specialized optimized solution for each given task with the minimal number of sensors.

The attention was concentrated on two types of wheeled mechanisms:

- two independent driven wheels on one axis and a third passive Castor wheel at the back or
- one driven axis and a third steering wheel in the front of the robot.

Various sensors were used for different purposes:

- photo sensors or optoelectronic couplers for the detection of lines,
- switches for the perception of contact,
- infrared sender and receiver for the measuring of the distance to an object and

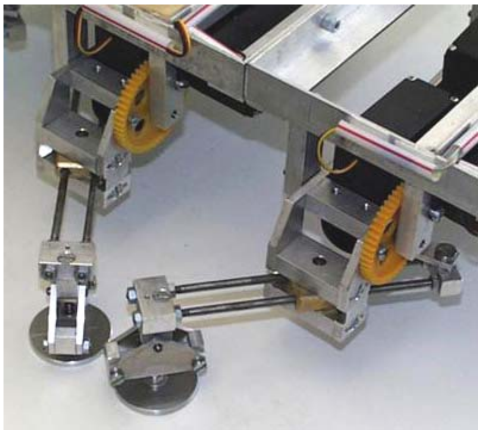

Fig. 2. Two legs during the tripod wave gait

- infrared beamer and receiver for the communication between robots.

Because of the lack of memory (32 kByte RAM) and computing power of the 6.270 board it was decided to look for individual solutions for each task implementing specialized and short algorithms.

Further possibilities for LEGO-robots were opened introducing the new RCUBE platform in connection with CMOS cameras.

III. The walking mechanism SimengDolores

In an educational project started in 1999 for a period of 2 semesters a team of students developed an autonomous walking machine using not more than 16 servo motors, an EyeBot controller [3], strain gauges and various materials plus a small budget, the support of the manufactory, books and the internet.

Inspired by well known walking machines the kinematical structure of the legs and the walking mechanisms was chosen:

- six legs each with two active and two passive degrees of freedom and
- an axis of symmetry with three legs on both sides.

The leg kinematics is very easy to control:

- one joint coordinate – the rotation about the vertical axis - is related to the forward-backward motion,
- the other joint coordinate operates the up-down motion of the leg.

The forward-backward motion of a leg is realized by a special kinematical mechanism so that it is parallel to the main axis of the robot. Consequently the forward-backward motion of the mechanism can be realized by a simultaneous forward-backward motion of all legs standing on the ground. Caused of the absence of a third active and passive joint the legs are to be in the neutral up-down position during the motion of the robot. Similar a up-down motion of the leg is allowed only if the leg is in the neutral forward-backward position.

The linear motion of the robot was realized using gaits defining the collaborations of the six legs. Three types of gaits were programmed:

- the tripod wave gait (Fig. 2),
- the forward equal phase gait and
- the follow the leader gait.

The control algorithms were developed on a standard PC using the programming language C and downloaded on the control unit based on the EyeBot-Platform with a Motorola 68332 microcontroller added by an additional I/O-board [7].

The main problems in this project caused on the one hand side in the to limited mobility of the mechanism and the constraints of power supply and on the other side in the absence of a sensor and vision system for the perception of the environment.

IV. Energy autonomy

Energy autonomy of a robot can be considered like a precondition for long service free working periods, lifelong learning or surviving in hazardous environment. Mobile robots working in a human environment can be recharged using electric power, other using solar energy or gas stations. Since 2002 different aspects of energy autonomy - the properties of control architectures, navigation strategies and docking concepts under lab conditions - were investigated.

The robot is capable to dock at the base stations and recharge itself (Fig. 3). A charge circuit board for autonomous 6.270-robots was developed and tested. Navigation and localisation of the base station is performed with an rotating laser beam and infrared beacons. The control architecture is a modified subsumption system, whose behaviours were provided with expectation horizons. These behaviours guarantee escalations, stress in more abstract activities and randomly selected actions at the top level, so that dead locks in the motion of the robot are avoided.

The robots survived self-governed more than 30 days in the laboratory until their external shut-down.

V. The Pioneer II – robots

Pioneer II is a family of two-wheel-drive robots [10]. They are small, intelligent. The architecture was originally developed by Kurt Konolige, containing all of the basic components for sensing and navigation in a real-world environment, including battery power, drive motors and wheels, position / speed encoders, and integrated sensors and accessories. They are all managed via an onboard micro controller and mobile-robot server software. It includes a complete addressable I/O bus for up to 16 devices and two RS-232 serial ports, one for communication between the robot server and a client computer and the other for the PTZ Robotic Camera.

Pioneer II comes with the Saphira client development suite with Colbert and the Pioneer simulator. It lets

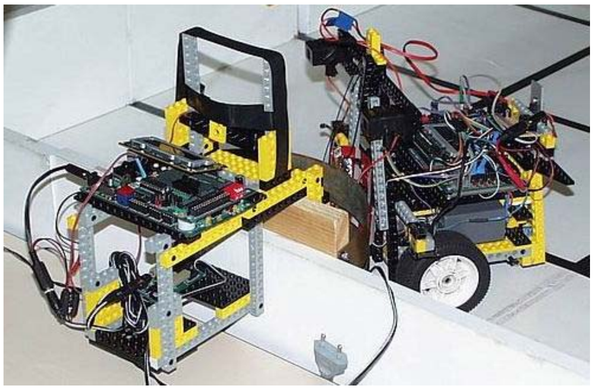

Fig. 3. Robots at the base station

enable several built-in robotic behaviours including collision avoidance, image recognition, and self-navigation.

Since 1998 the Pioneer II platform has been used as the experimental base in practical exercises, in various research activities and diploma theses. Basic features of motion planning, programming and control, of using sensors and vision systems, of different navigation schemes or mobility and autonomy were studied. In student experiments simple applications were realized using the hard- and software features of the robot system, including user defined behaviours and activities [8], [9].

A. Get a bottle from outside of the lab

The standard experiment done at the end of the course consists of a sequence of subtasks:

- move along the wall up to a door is detected,
- move throw the door stopping in front of the glass wall,
- move along the corridor avoiding collision up to detecting bottles on the right hand side,
- move near to the bottle with the red label, grasp and heave it,
- return to the starting point.

For the solution of this task the encoders, the sonar system, the robot vision, the internal map and the built in intelligence of Saphira can be used. An algorithm for the detection of the bottles and, especially the bottle with the red cap must be integrated.

B. Vision based toy collection

The main goal was to build a complete, autonomous and robust robot system collecting toys in a “children room” and placing them in a box (Fig. 4). The robot PIONEER II equipped with an active on-board camera was used to solve the task under lab conditions with a predefined and marked working area, a unchanged ground and normal, unstable light. Three subtasks had to be solved:

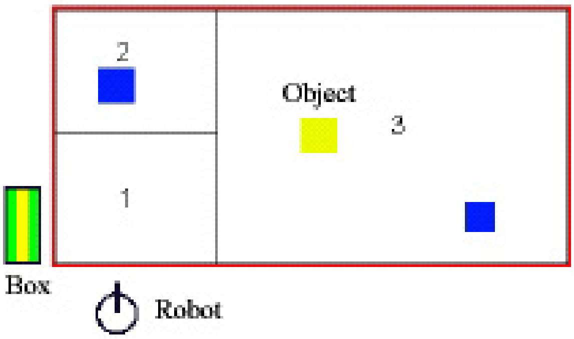

Fig. 4. Scheme of the "children room"

- to find an object on the ground using image recognition techniques,
- to grasp the object and put it into the box,
- to collect all objects in the marked area (Fig. 4).

The subtask to handle one object was divided in five steps:

- look for an object,
- move to the object,
- grasp the object,
- move to the box,
- put it into the box,

each of them correspondents to a Colbert activity.
This subtask has to be repeated up to all objects are collected.
The solution of the subtask to collect all objects in the marked area is pre planed:

- first, the region 1 in front of the starting position of the robot is scanned before the robot starts to clean it from objects; after putting the object into the box the robot returns to the starting point (because of the invisible area of 40 cm around itself).
- second, the region 2 is cleaned in a similar way starting each time from a point in front of the box,
- third, the region 3 was cleaned starting at the border between regions 2 and 3 and moving step by step to the right up to all objects are collected. After that the robot returns to the starting position.

Some experiments showed that the proposed solution works well (Fig. 5).

The problems solving advanced tasks with the PIONEER platform are located in the vision system especially in unreliable video and control radio links and the difficulties to adapt control algorithms inside the Pioneer and Saphira operational system.

VI. RCUBE - a hardware platform

Small autonomous systems especially mobile robots are a growing application area of intelligent systems. The economic commission of the UNO forecasts a boom concerning service robots (for instance for medical, cleaning, security purposes) and personal

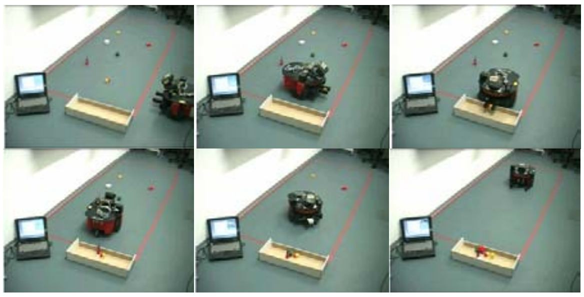

Fig. 5. Sequence of activities of the robot

robots (domestic and entertainment robots) till 2005 [4].
For reasons of cost, time and capacity small enterprises and universities normally use widely spread basic blocks of microcontrollers (such as Basic Stamp, Handy board, C-Control) not suitable for real robotic applications including manifold sensor equipment (Table 1). For small and middle size autonomous systems the most important problems are the limited number of connections for sensors and actuators, the low computing performance and high power consumption.
Another drawback is the lack of an autonomous image recognition capability. Image recognition is realized on mobile robots either via radio linked hardware or by using relatively power consuming components.
In 2001 the project to develop a new intelligent platform for autonomous systems with vision capabilities sponsored by the Ministry of Sciences and Culture of the state Brandenburg/ Germany was started.

A. Requirements and results

The technical requirements to robot platform were identified as follows:

- image recognition onboard
- low power consumption
- high computing performance
- program persistence
- software open source
- independent from any radio links
- 32 ports for digital and analogous sensors
- 12 ports for actuators, servos, DC-motors, bulbs
- small and modular
- cost effective

The RCUBE platform should be available in various configurations dependent on the demands of the application, for example (Fig. 6) like a:

- cost-effective platform for reactive robots and private developers,
- powerful platform for intelligent robots with image processing capabilities suitable for research, development and education in the field of service robotics.
- The architecture RCUBE consists of three of 3 ready-to-program hardware modules with a basic software layer:

Table 1. Overview about controlling parts for reactive robots
(Costs in Euro of one robot and time in month to build a simple robot are estimated)

System	Source	Sensors	Actuators	Costs	Time
Eyebot	JokerRobotics	Many	many	700	3
6.270-Board	self assembly	Many	many	600	3
Handyboard	self assembly	Few	many	600	3
C-Control	Conrad electronics	Few	very limited	450	3
Basic-Stamp	Parallax	Few	very limited	350	2
RCX	LEGO	very limited	few	260	1
Mobile-Robot	Fischertechnik	very limited	very limited	300	1
Real Robots	Eaglemoss	Few	very limited	200	1
AKSEN	UAS Brandenburg	Many	Many	400	1

- CPU board
- VIO board (video input/output unit)
- AKSEN board (actuator/sensor unit)

They can be combined in any number and connected via a field bus with 1 MBit bandwidth. Various interesting configuration and application are imaginable. A simple vision test equipment is shown at Fig. 7.

B. CPU board

The CPU Board provides the location of computing power and therefore the intelligence of the system. A StrongARM processor with 200 MHz running ARM-Linux is its core component. It is programmable like any Linux machine using gcc. Libraries for communication with other modules are provided. Downloaded programs can be flashed to a nonvolatile memory.
For logging purposes or for receiving high level orders, a bluetooth connection with 115 KBit bandwidth is optional available. This provides a comfortable way for development and debugging.

C. VIO board

The VIO Board is a standalone image digitizing and recognition solution based on StrongARM and Linux. Up to 4 standard PAL cameras (for instance small and cheap CMOS cameras) can be connected to the board (multiplexed, 60 ms for a camera change).
The image stream is digitized with 25 fps (CCIR601 CIF 2:1, means 320x280x24) or 10 fps (CCIR601 full resolution 1:1). The image stream is provided in RGB or YCbCr format. Image recognition algorithms are programmable in C or C++ and connected to the image stream via a Video4Linux2 interface.
To support the development a video output of the input stream and the image analyzing results, such as coloured segments, is available in real time.

D. AKSEN board

The AKSEN board provides connections for simple peripheral devices in a robotic environment, such as actuators and sensors. It was designed with two main purposes in mind:

- standalone controller for reactive robots,
- sensor and actuator server in a RCUBE system.

Main features of AKSEN controller board are

- 15 analogous inputs (suitable for sensors for light, infrared, obstacles, lines, voltage etc.)
- 16 digital in-/outputs (freely configurable)
- 4 motor drivers for small DC-motors up to 1A (variable in direction and rotational speed)
- 4 driver (for infrared senders or bulbs)
- 3 servo outputs (extensible by software)
- 1 output for modulated infrared (localization)
- 3 fast encoder inputs (odometry)
- 4 dipswitches
- RS232 interface,
- CAN interface (optional)
- LCD display (optional)
- bluetooth connection (optional)

It is programmable like any Linux or Windows machine using freeware c compiler like sdcc.

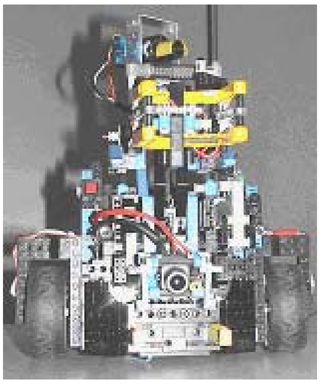

Fig. 6. RCUBE robot with vision capabilities

VII. Conclusion

Based on the experiences in investigating and teaching robotics for a long time and the practical success and failure with the 6.270 board, the EyeBot controller and the PIONEER II platform the RCUBE system was developed consisting of three main modules:

- CPU board,
- VIO board and
- AKSEN board.

Any module is designed for low power consumption and interoperability and can be used standalone or combined in any number collaborating and communicating via CAN-bus or bluetooth with other modules or hosts. Each module survives a power blackout (or a long inactive period) without loosing data and reboots after power reoccurs.

The CPU Board based on a StrongARM processor (200 MHz, 32 MB RAM, ARM-Linux) provides necessary computing performance allowing the implementation of algorithms for task planning, navigation or skill learning.

The VIO-board allows really autonomous image processing for up to four cameras independent of radio links and base stations.

The AKSEN-board provides connections to usual devices of small robots (15 analogous inputs, 16 digital in-/outputs, 4 motor drivers for small DC-motors, 4 drivers for infrared senders or bulbs, 3 servo outputs).

The flexible configuration of a RCUBE system provides interesting application areas:

- reactive mobile robot (only AKSEN-boards),
- reactive mobile seeing robots (AKSEN-board and VIO-board),
- intelligent cameras (CPU board and VIO-board),
- planning robots (CPU Board and AKSEN-board)
- small service or personal robots (all three or more boards).

The system will be suitable as a research and education platform for universities, a basis for industrial applications and for private developers of robots.

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